

REINFORCED THIN WALL THERMOPLASTIC STORAGE VESSEL  
MANUFACTURE

This is a continuation in part of  
application Serial No. 10/267,723, filed October 10,  
2002 and now abandoned.

BACKGROUND OF THE INVENTION

This invention relates generally to a method  
for reinforcement of hollow thermoplastic storage  
vessels with one or more wraps of continuous fibers  
and more particularly to a means for improved bonding  
between the applied fibers and the outer vessel  
surface for storage vessels having relatively thin  
walls.

In a co-pending application Serial No.  
09/327,003 entitled "Reinforced Thermoplastic Pipe  
Coupling" and filed June 7, 1999 in the names of David  
E. Hauber, Robert J. Langone and James A. Mondo which  
is now United States Patent 6,164,702 and also  
assigned to the present assignee, there is disclosed a  
continuous fiber reinforced thermoplastic pipe  
coupling having improved resistance to applied stress  
when used with pipe lengths being joined together.  
The fiber reinforcement is aligned during placement in  
a particular manner and placed at predetermined fiber  
angles dictated by mechanical forces being applied  
such as by internal fluid pressure in the coupled pipe  
lengths. Said already known method for construction  
of said reinforced thermoplastic pipe coupling  
includes a controlled directional orientation of the  
fiber component to enable the fiber placement to be  
fixed for maximum effectiveness in withstanding the

particular stress being generated when the joined  
together pipe lengths are customarily used for the  
transfer of pressurized fluids. Since the fiber  
materials currently used in this manner are generally  
stronger than the polymer matrix compositions now also  
being employed, the overall strength produced in the  
composite member depends largely upon the fiber  
placement direction for the particular end product.  
The fiber reinforced coupler is thereby only as strong  
as the spatial direction of the included fibers with  
respect to the direction of the internal stress when  
applied to said member. Thus, when the fiber  
reinforced coupler is stressed by internal fluid  
pressure in the direction of the fiber placement, the  
applied load is withstood primarily by the included  
fibers and the coupler strength in resisting such  
stress is at a maximum value. Conversely, when the  
composite member is stressed in a perpendicular  
direction to the fiber direction, the applied force  
must necessarily be resisted primarily by the polymer  
matrix so that the coupler strength is at minimum.  
The relative amounts of the individual stresses being  
applied to the fiber reinforced coupler must also  
necessarily be considered for proper fiber placement  
direction. For an externally unconstrained  
installation of said previously disclosed pipe  
couplings, such as encountered with the above ground  
pipe installations, the applied loads can be examined  
by treating the joined pipe lengths as a pressure  
vessel. From such analysis it was found that the  
stress applied to the pipe wall in the hoop direction  
is twice an amount as the applied stress in the pipe's

axial direction. Employing well recognized shell theory calculation, it was further found that a fiber angle of 55 degrees was needed to balance these applied loads assuming 90 degrees to be in the pipe hoop direction and 0 degrees to be aligned in the direction of the pipe longitudinal axis. For constrained pipe installations, however, such as in-ground or having the pipe ends being held there, there can only be need for resisting hoop stress.

Accordingly, fiber placement at or near a 90 degree angle with respect to the longitudinal pipe axis was dictated while further recognizing that some angle less than 90 degrees may only be achievable with the fiber winding in the customary manner. The entire contents of said referenced co-pending application are hereby specifically incorporated into the present application.

It can readily be appreciated that thermoplastic storage vessels undergo similar internal stress when being utilized. Accordingly, the effectiveness of fiber reinforcement for thermoplastic storage vessel will also depend to a considerable degree upon the same factors previously considered with respect to said reinforced thermoplastic couplings. For example, a thermoplastic storage vessel having a cylindrical configuration can generally have the fiber wraps applied in a hoop direction for maximum reinforcement whereas a spherical storage vessel will understandably have the fiber placement angle varied in different spatial directions. It has now been found, however, that thermal bonding the reinforcement fibers to the outer

surface of the thermoplastic storage vessel in the same manner previously employed for reinforcement of said thermoplastic pipe couplings produces inferior results. Specifically, the previously employed bonding method provided sufficient thermal expansion of the thermoplastic inner coupling member when being carried out that an effective thermal bonding with the applied fiber replacement took place. This does not reliably occur for various shaped thermoplastic storage vessels having a lesser wall thickness. It thereby becomes necessary for said relatively thin wall storage vessels to adopt an improved thermal bonding procedure for the fiber reinforcement to have the desired effectiveness.

It is an important object of the present invention, therefore, to provide a novel method and apparatus to reinforce thin wall thermoplastic storage vessels with one or more wraps of applied continuous fiber.

It is still another object of the present invention to provide a novel method and apparatus to secure the applied fibers to the outer surface of a thin wall thermoplastic storage vessel so as to better resist internal stress when the storage vessel is in use and prevent delamination when pressure is released.

Still another object of the present invention is to provide a novel method and apparatus for reinforcement of a thin wall thermoplastic storage vessel which includes a plurality of continuous juxtapositioned fibers being reliably secured to the outer surface of said storage vessel so as to be

aligned in a predetermined spatial direction resisting applied internal stress during vessel use.

These and still further objects of the present invention will become more apparent upon considering the following more detailed description of the present invention.

#### SUMMARY OF THE INVENTION

It has now been discovered by the present applicant that a contemporaneous pressurization of the internal cavity in a thin wall thermoplastic storage vessel while the applied reinforcement fibers on the outer surface of said storage vessel are being thermally bonded thereto overcomes the problem previously experienced with inadequate joinder of said reinforcement means. The internally applied pressure is seen to avert buckling or wrinkling of the thin storage vessel wall while being heated sufficiently for joinder between the reinforcement fibers and the outer vessel surface thereby enabling a sufficient bonding action therebetween. Internal pressurization of the storage vessel can thereafter be discontinued in the present reinforcement method allowing the fiber wrapped storage vessel to cool upon termination of said thermal bonding action. Accordingly, the present method to reinforce said type thin wall hollow storage vessel comprises wrapping a plurality of continuous juxtapositioned reinforcement fibers formed with a material composition selected from the group consisting of ceramics, metals, carbon, glass compositions and organic polymers while in an unbonded condition about the outer surface of said storage vessel, heating the outer vessel surface sufficiently

to cause thermal bonding between the reinforcement fibers and said outer fiber wrapped vessel surface, contemporaneously pressurizing the interior cavity of said rotating fiber wrapped storage vessel with a  
5 coolant medium during said heating step, and allowing the fiber wrapped storage vessel to cool upon terminating said heating step before discontinuing pressurization of the vessel interior cavity. Various liquid or gaseous coolants can be employed in the  
10 present method to include water, air, nitrogen or the like, while removal of said coolant medium from the storage vessel after being heated during the present thermal bonding step can assist final cooling of said reinforcement fiber wrap vessel. Thermal bonding in  
15 the present method involves some melting of the thermoplastic material being employed so that melting of the thermoplastic outer vessel surface occurs which can be accompanied by melting of a thermoplastic matrix included in the applied fiber reinforcement.  
20 Accordingly, a softening or melting action takes place during the present thermal bonding step between the outer surface of the thermoplastic storage vessel and any thermoplastic polymer materials serving as the matrix composition in selected preformed tape  
25 embodiments having the continuous reinforcement fibers thereafter becoming permanently bonded therein.

The herein defined fiber reinforcement method understandably enables a wide variety of fiber materials to be selected as previously pointed out.  
30 Thus a reinforcement fiber material can be selected from the aforementioned class of suitable materials so long as it is mechanically stiffer than the selected

thermoplastic vessel polymer and has a glass transition or melting temperature higher than the surface temperature of the thermoplastic vessel during use. Selected polymer fibers can understandably include continuous bare filaments and commingled continuous fibers which can be wetted by polymer melt flow in the above described heat bonding procedure. For selection of a suitable preformed continuous fiber material or prepreg tape having a matrix formed with a thermoplastic polymer, said matrix polymer is desirably chosen to have a softening or melt temperature equal to or lower than the softening temperature of the selected vessel polymer. Any suitable heating source can be used in the present method to reliably bond the applied fiber reinforcement to the outer thermoplastic vessel surface. Contemplated heat sources include but are not limited to inert gases, oxidizing gases and reducing gases, including mixtures thereof, infrared heating sources, such as infrared panels and focused infrared means, conduction heating sources such as heated rollers, belts and shoe devices, electrical resistance heating sources, laser heating sources, microwave heating sources. RF heating sources, plasma heating sources and ultrasonic heating sources. An external flame heating source provides economical heating with high-energy densities and with the gas burner or burners being suitable designed so as to heat the outer circumference of the fiber wrapped thermoplastic vessel. In a preferred embodiment, the wrapped storage vessel is rotated about the selected heat source while having the interior cavity of said

storage vessel being subjected to a pressurized condition. The applied pressure can desirably produce some radial expansion of the storage vessel wall thereby further enhancing the thermal bonding action taking place. The applied pressurization can also be initiated prior to said heating step in the present method with applied pressures of ten pounds per square inch or more having been found effective.

The fiber alignment selected in the present method can also vary with the particular shape of the thermoplastic storage vessel being reinforced in said manner. Thus, a cylindrical shaped thermoplastic water heater can have one or more wraps of the reinforcement fibers aligned in a hoop or helical direction whereas a spherical thermoplastic storage vessel for the same use can understandably be wrapped in different spatial directions. A means of preserving the fiber alignment in the present method until the melted polymer in physical contact therewith again becomes solid can require that said fibers be subjected to appropriate applied mechanical force during the thermal bonding action. Such manner of fiber placement can be carried out by employing external tension winding means to guide the fiber reinforcement while being wound around the outer vessel surface. An alternate means for retaining the fiber alignment is a compaction roller to apply mechanical pressure to the heated fiber and polymer materials while being bonded together. Use of a compaction roller in such fiber placement can apply an external compaction force with zero tension being applied if desired although it is within contemplation

of the present invention for both forms of external mechanical energy to be employed together when found beneficial. Another advantage of compaction roller use is the ability to orient such means in any spatial direction enabling fiber placement at a predetermined fiber angle dictated by the contour of the particular storage vessel being reinforced in said manner. Thus, a cylindrical shaped thermoplastic pressure vessel can have one or more wraps of the reinforcement fibers aligned in a hoop or helical direction whereas a spherical thermoplastic storage vessel for such use can be wrapped in a different spatial direction.

Following termination of said thermal bonding step in the present method, the fiber wrapped storage vessel can be allowed to cool in the ambient atmosphere. Such cooling can be carried out in various ways to include removal of any pressurization liquid or gas coolant heated during the thermal bonding procedure as well as actively cooling with an applied coolant medium. The completed fiber reinforcement can now serve to enable sufficiently higher operating pressures in said storage vessel than otherwise permissible. Employment of the present method upon an otherwise conventional thermoplastic pressure vessel having a closed end cylindrical configuration has produced this result. Additionally, an outer protection or decorative coating to include heat shrinkable tubing, wrap or extruded coatings and the like can be applied to said fiber reinforced thermoplastic storage vessel in a conventional manner for protection of the fiber reinforcement from environmental or mechanical damage and/or corrosion.

BRIEF DESCRIPTION OF THE DRAWING

Figure 1 is a block diagram illustrating successive processing steps which can be employed in carrying out the method of the present invention.

5           Figure 2 is a side view for a representative thermoplastic storage vessel being reinforced according to the present invention.

          Figure 3 is a schematic side view for a representative fully automated apparatus carrying out the fiber reinforcement method of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to the drawings, Figure 1 is a block diagram representation illustrating the sequence of processing steps employed according to the present invention for fiber reinforcement of a representative thermoplastic storage vessel having a closed end cylindrical configuration. The depicted fiber reinforcement process 10 employs a typical six inch diameter, thirty-two inch long thermoplastic liquid container 12 having a 0.14 inch wall thickness which has one or more wraps of the thermoplastic reinforcement fibers 14 helically wound about the outer cylindrical surface of said storage vessel. One or more tie wraps 16 of said thermoplastic reinforcement fibers can also be subsequently applied in the hoop direction for the purpose of carrying the radial stress in the cylindrical pressure vessel. Said fiber wrapped vessel 18 next undergoes thermal bonding of the applied fiber reinforcement to the outer vessel surface. In a preferred embodiment, the fiber wrapped vessel is rotated about its central axis

20 while heating the outer vessel surface with a  
conventional heat source 22. Heating of the fiber  
wrapped vessel in said manner produces some melting of  
the outer vessel surface which upon vessel cooling  
5 retains the originally applied spatial orientation of  
said fibers. During said heating step the hollow  
interior cavity of said fiber wrapped storage vessel  
18 is pressurized 24 by various means to avoid any  
significant wrinkling or collapse of the vessel wall  
10 that could understandably deter a fully bonded  
condition for the applied fiber reinforcement.  
Internal pressurization of the storage vessel can be  
initiated before thermal bonding of the fiber  
reinforcement while thereafter being discontinued when  
15 the thermal bonding step has been completed and the  
reinforced storage vessel then being allowed to cool  
26. Terminating pressurization of the storage vessel  
28 can also be carried out in various ways. To  
further illustrate a suitable vessel pressurization in  
20 the present method, the interior cavity of the fiber  
wrapped storage vessel 18 can be filled with a liquid  
coolant, such as water, glycol, alcohol and the like  
before the above described heating step is begun as  
well as thereafter being removed from the storage  
25 vessel after becoming heated during said processing  
step. Alternately, the interior cavity of said  
storage vessel 28 can be actively cooled with a  
suitable gaseous coolant to include air, nitrogen or  
other inert gas while the thermal bonding step is  
30 being carried out and with said cooling action being  
discontinued when the reinforced storage vessel is  
thereafter allowed to cool. Active cooling of the

fiber wrapped storage vessel in said manner at a pressure of 10 PSI or more has been proven satisfactory in the present method.

As herein pointed out, the fiber direction of the underlying fiber layers for the illustrated cylindrical storage vessel is directed primarily by the ability of said reinforced storage vessel to withstand internal fluid pressure when such vessel is put into service. It can be readily be appreciated, however, that other storage vessels having a different shape, such as a sphere or entirely open-ended cylindrical shape, can have the fiber alignment in an overall hoop direction for better resistance to internal fluid pressures during use. Additionally, the continuous fiber reinforcement can be applied in the present method by various means. A selected amount of tension can be exerted upon the continuous fibers when being applied to assist with retention of the predetermined or juxtapositioned fiber angle with respect to the vessel longitudinal axis in the herein illustrated embodiment. Similarly, a mechanical compaction force exerted upon said fibers during initial placement or subsequent thermal bonding can be employed for this purpose. A wide variety of thermoplastic polymers can also be selected as the material of construction for storage vessel being reinforced according to the present method. Suitable organic polymers include but are not limited to polyethylene such as high density polyethylene and medium density polyethylene, polypropylene, polyphenylene sulfide, polyetherketoneketone, polyamide, polyamideimide and polyuvinylidene

5 difluoride. A similar wide variety of materials are found suitable as the fiber reinforcement in the present method to again include but not be limited to ceramics, metals, carbon aramid and other organic polymer fibers having softening temperatures above that of the storage vessel in use and glass compositions such as E type and S type glasses. Moreover, said fiber materials can also be applied in various structural forms to include a parallel  
10 alignment of the bare fibers and conventional fiber tapes having the continuous parallel oriented fibers bonded together in a thermoplastic polymer matrix. The optional use being made of tie layers 16 in the presently illustrated embodiment can also serve to  
15 help retain the juxtapositioned spatial orientation of the applied fiber reinforcement when selected thermoplastic polymer materials being employed are not miscible during the heating step.

Figure 2 is a side view for a representative  
20 thermoplastic storage vessel being reinforced according to the present invention. More particularly, the depicted cylindrical thermoplastic storage vessel 30 is repeatedly illustrated during each processing step described in the preceding  
25 preferred embodiment. As shown, said storage vessel 30 comprises an elongated thermoplastic cylinder 32 having a closed end 34 and an open end 36 fitted with a conventional inlet coupling 38. There is next depicted the manner whereby the continuous  
30 reinforcement fiber 40 having a thermoplastic resin binder is deposited on the outer surface 42 of the rotating thermoplastic storage vessel in a

conventional helix pattern 44 while also being subjected to a tensile force being applied in further customary manner. The next processing step being illustrated depicts further rotation of the fiber wrapped storage vessel 46 while additional fiber wraps 48 are applied in a hoop direction enabling better retention of the underlying reinforcement fiber 40. The still further depicted processing steps in the herein illustrated method of fiber reinforcement demonstrate the heating step being employed to cause thermal bonding between the applied unbonded reinforcement fibers and the outer surfaces of said storage vessel. In doing so, a conventional heat source 50 positioned in relatively close proximity to said fiber wrapped storage vessel 46 supplies the needed thermal energy during said bonding procedure and which is further accompanied by having the interior cavity 52 of said pressurized fiber wrapped storage vessel cooled with a selected liquid cooling medium 54 while said thermal bonding step is being carried out. Following said latter procedure, the reinforced storage vessel 56 is allowed to cool in the ambient atmosphere which further includes removal of the cooling fluid after sufficient time has elapsed for resolidification of the polymers thermally bonded together.

Figure 3 depicts a representative fully automated apparatus to conduct the required thermal bonding procedure according to the present invention. More particularly, apparatus 60 includes structural support means 62 enabling rotation of an already fiber wrapped storage vessel 46 in the ambient atmosphere.

Motor driven releasable support members 64 and 66 disposed at both ends of the supported vessel respond to commands provided with a conventional program controller 68 or equivalent data processor, such as a software programmed computer. Said control means is preprogrammed to automatically start and stop all operations required in the present thermal bonding procedure responsive to the given commands.

Accordingly, the preprogrammed instructions are provided to said program controller for automated operation of all component mechanisms incorporated in the depicted apparatus according to a predetermined sequence. Supply means providing suitable liquids and gases to the suspended vessel during the thermal bonding procedure are further included in the depicted apparatus. Gas inlet 70 is connected to the suspended vessel via a conventional flow valve 72 for this purpose as is similarly connected liquid inlet 74. Still further included component mechanisms in the depicted apparatus include electrical supply 76, natural gas supply 78, liquid and gas coupler member 80, connected to inlet vessel fitting 82 and a liquid drain member 84 also connected to the suspended vessel 46. Natural gas fired burner 86 is positioned in close proximity to the suspended vessel and is supplied from gas inlet 78. While not shown in the present drawing, conventional motorized variable speed drive means connected to suspended vessel 46 can be further included in the present apparatus for rotational speed variation when reinforcing different vessel sizes and shape in accordance with the present invention.

In fully automated operation, the Figure 3 apparatus follows a programmed sequence of procedures responsive to the given commands of program controller 68. Such operational sequence commences with the  
5 already fiber wrapped storage vessel 46 being clamped between support members 64 and 66 for vessel rotation while further sealing the vessel inlet opening 82. The suspended vessel is next internally pressurized with said instruction program to a preprogrammed  
10 pressure above atmosphere pressure with a suitable gaseous medium such as air and the like. The now internally pressurized vessel is then instructed with said program to rotate at a preprogrammed rotational speed. While continuing vessel rotation, gas fired  
15 burner 86 is next actuated for a preprogrammed time period again with said instruction program to commence external heating of the vessel outer surface. As can be seen in the Figure 3 drawing, the illustrated burner configuration enables both dome ends of the  
20 rotating fiber wrapped vessel to be heated concurrently with the central vessel region. A suitable liquid coolant, such as a water spray is also admitted to the hollow rotating vessel for a preprogrammed time period during the preprogrammed  
25 heating cycle. Such contemporaneous cooling means is provided to the vessel from inlet 74 via flow valve 72 and rotary coupler 80. The vessel end of liquid drain member 84 is next inserted into the hollow vessel cavity again pursuant to the automated instruction  
30 program while thereafter allowing the admitted coolant to be subsequently removed. Automated retraction of said drain member proceeds while the fiber wrapped

storage vessel is being allowed to cool in the ambient atmosphere. Internal pressurization of the vessel is not relieved with the programmed instruction until sufficient vessel cooling has occurred. Said instruction program can still further include automated final release of the processed vessel from the present apparatus after vessel rotation has been terminated.

The above described apparatus enables fiber reinforcement of various cylindrical thin wall thermoplastic storage vessels in a significantly improved manner. Limited external heating of the fiber wrapped vessel in the present apparatus can be expected to produce a superior final product in several respects. Since only the outer surface of the underlying storage vessel undergoes any melting in the present apparatus for satisfactory thermal bonding of the reinforcement fiber to the outer wall surface, the original physical and chemical characteristics of the underlying vessel polymer remain substantially unchanged. It is well recognized that polymer melting can produce serious defects in the resolidified polymer including thermal degradation of the material itself as well as contributing to an increased thermally induced residual stress condition. Contemporaneous liquid cooling of the inner vessel cavity while thermal bonding the applied fiber reinforcement to the outer vessel wall surface in the present apparatus is carried out further helps keep the vessel polymer unmelted. Still further, retaining internal pressurization of the fiber wrapped vessel in

the present apparatus until the vessel has cooled promotes greater fiber bonding in the final product.

It will be apparent from the foregoing description that a broad useful and novel method and apparatus has been provided to a reinforce thin wall thermoplastic storage vessel with one or more wraps of applied continuous fiber. It will be apparent, however, that various modifications can be made in the disclosed process and apparatus without departing from the spirit and scope of the present invention. For example, it is contemplated that some heating of the unbonded reinforcement when being initially applied to the outer surface of the storage vessel can assist in having the fiber conform more closely to the particular contours of the vessel surface. Likewise, it is contemplated that other organic polymers, other vessel shapes and other processing equipment configurations than herein specifically disclosed can be substituted in carrying out the present method. Consequently, it is intended to cover all variations in the disclosed reinforcement method and apparatus which may be devised by persons skilled in the art as falling within the scope of the appended claims.